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Introduction

Chemical stockpiles that consist of chemical warfare agents and their containers remain in finite quantities and in various degrees of repair at nine U.S. Army installations.[1] Congress and the Chemical Weapons Convention are committed to destroying the entire stockpile by the year 2007.[2] Achieving this goal, in most instances, will be by incineration. Unlike standard risk assessments that evaluate chemical releases that have historically occurred, Chemical Stockpile Incinerator (CSI) risk assessments anticipate the attendant risks to human and ecological receptors in the vicinity of planned incinerators. They also determine whether or not a CSI can first be constructed, or appropriately engineered in the case of those already in the construction phase, through the use of a pass/fail determination scheme. Procedurally, CSI risk assessments model incinerator combustion products as they are: 1) released into the air as stack emissions; 2) deposited onto soil, plants, and waterbodies; and 3) taken up into certain terrestrial and aquatic biota. Modeled chemical-specific

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1 *See* National Research Council, *Recommendations for the Disposal of Chemical Agents and Munitions* (1994).

2 *See* U.S. Arms Control and Disarmament Agency, *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction* (October 1993).

concentrations in each instance are then used to evaluate applicable routes of exposure in human, and non-human, species. Contaminant fate and transport process information is used to assist the modeling effort, as well as site-specific meteorological data when it exists.

The level of trust and confidence in CSI risk assessment outcomes needs to be at a near maximum level for two reasons. First, because CSI risk assessments precede construction of the incinerators they are evaluating, only predictive risk assessment methods can be used. There is no opportunity for field verification of estimated results (e.g., estimated soil concentrations resulting from stack emissions). Thus, CSI risk assessments bear an inherent and unavoidable uncertainty term that the risk manager must confront when reviewing the assessment's findings. Second, there is a great deal riding on a "pass" outcome when employing a pass/fail assessment determination scheme. A planned CSI will only operate long enough to incinerate the finite quantities of chemical stockpile presently stored at specific Army installations, with the longest incineration period estimated to be six years. In effect, a "pass" sanctions the expenditure of up to $1 billion for planned, or ongoing, construction of a one-time use incinerator with a period of performance as brief as two years. A "pass" is in effect saying that during CSI operation, or in a specified post-operation period, there are no unacceptable risks to human or ecological receptors within a 50 kilometer radius of the proposed incinerator site.

Can the supporting incinerator risk assessment guidance assume such awesome responsibility and provide the assurance that CSIs, when operational, are protective of nearby receptors? There is reason to suspect that it cannot. Existing health risk assessment guidance for combustor emissions was developed for applications with conventional (i.e., long-term or ongoing operation) combustion facilities, and not for the single-release event, short-term operations that typify a CSI.[3]

3 *See* N.C. Dep't of Health, Env't, and Natural Res., *North Carolina Protocol for Performing Indirect Exposure Risk Assessment for Hazardous Waste Combustion Units* (January 1997); U.S. Envtl. Prot. Agency (U.S. EPA), *Methodology for Assessing Health Risk Associated With Indirect Exposure to Combustor Emissions: Interim Final* (1990); U.S. EPA, *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions* (1993); U.S. EPA, *Risk Assessment Implementation Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste* (April 22, 1994); U.S. EPA, *Errata, Risk Assessment Implementation Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes* (1994);

Whereas the guidance acknowledges the proliferation of conventional incinerators that provide an alternative means to land disposal of municipal solid waste and sewage sludge, it fails to identify the need to evaluate risks from CSI releases, and neglects to mention this unique brand of incinerator altogether. Given these concerns, the supporting guidance was evaluated for its capability to support critical pass/fail determinations at a CSI. An analysis of three elements of CSI risk assessments that commonly relate to constituent quantities in soil — 1) the characterization of the background condition; 2) the estimation of constituent concentrations in both surface and subsurface soils; and 3) the evaluation of risk at an installation's fenceline — reveals inadequacies in the guidance that can arguably lead to unreliable, and underestimated, assessments of risk.

Background Characterization

The available guidance offers two approaches for characterizing background in terms of constituent levels, with "background" defined as the pre-existing (i.e., prior to CSI operation) environmental media concentrations at locations within a 50-kilometer radius of a CSI, where actual or hypothetical receptors are to be placed and evaluated.[4] Either a default baseline risk level may be assigned to the locations, acknowledging the presence of constituents from other sources already there, or field sampling may occur. Superficially, the guidances' default levels appear generous in ascribing baseline risk to critical site locations. Conventionally, a Hazard Index (HI) of 1.0 (indicating that a receptor's chemical intake and a safe dose are the same) is taken to represent a threshold-for-effect level in noncancer assessments. The guidance recommends assigning a noncancer HI for human health risk of 0.75 at the locations in recognition of potential hazard-posing contaminants that stem from sources other than the planned CSI. An apparently conservative stratagem that sets the baseline hazard level to 0.75 means that the estimated noncancer HI attributable to the CSI must not be any greater than 0.25 in order for the CSI to "pass" the

U.S. EPA, *Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes* (December 14, 1994); U.S. EPA, *Risk Assessment Support to the Development of Technical Standards for Emissions From Combustion Units Burning Hazardous Wastes* (1996).

4 *See* U.S. Envtl. Prot. Agency (1990), (1993), (April 22, 1994), *supra* note 3.

first tier risk assessment that supports a construction permit. However, use of the 0.75 baseline hazard level may be underprotective in the case of metals, as discussed below, with regard to estimated surficial soil concentrations. Similarly, the guidance recommends that at the critical locations, there be no greater than 1E-05 excess cancer risk attributable to the CSI. This default adds a full order of magnitude of stringency to CSI pass/fail determinations over that which characterizes the "trigger" for remedial action considerations in the EPA's Superfund Program.

Although not stated in the guidance, the rationale for the non-requirement to sample may be the excessive cost involved with chemical analysis. Typically, there may be as many as 100 or more constituents within a combustion facility's emissions stream that are of interest within a risk assessment framework. Furthermore, 10% of these are dioxins and furans, which are more expensive analytes to test for. Regardless of the rationale behind the guidances' providing options for addressing the baseline condition, it is important to note that the sampling approach has yet to be exercised in CSI risk assessments. This may be unfortunate, for a baseline sampling effort could reveal that the surrounding environment already bears unacceptable risk levels for human and ecological receptors. Such a case is reasonable, considering that most of the Army's proposed CSI locations have within their critical radius one or more significant contamination sources, many in the form of an operating Conventional Incinerator Complex (CIC). As an example, in a recent CSI risk assessment, a CIC was located approximately six kilometers from the proposed CSI location, and had been in operation for 20 years.[5] Although the processes feed at a CIC differs from that of a CSI, the emission stream constituents are quite similar to those of a CSI. In this case then, accumulated quantities of constituents from the CIC alone may have been responsible for a HI in excess of 0.75. In that event, the guidances' default risk level would not have been sufficiently protective.

The non-requirement to sample the baseline condition overlooks a fundamental issue that a CSI risk assessment needs to address: "Is the

5 *See* U.S. Army Center for Health Promotion and Preventive Medicine, *Final Screening Risk Assessment, Resource Conservation and Recovery Act Part B, Risk Assessment No. 39-EJ-1401-97, Pine Bluff Chemical Agent Disposal Facility, Pine Bluff Arsenal, Pine Bluff, Arkansas* (1997).

proposed CSI location, and its surrounding environment, already too contaminated to receive the additional constituent loadings that a future incinerator would be contributing?" Should the environment be too contaminated, either significant design changes for the incinerator would have to occur, or an alternative technology for the destruction of a stockpile would have to be considered. Shortcomings of the guidances' default baseline risk levels become apparent when two critical realizations are made. First, as there are no outright barriers to the collection of background data, the absolute baseline condition could be known. Considering the multitude of uncertainty sources in CSI risk assessments, collecting background data could eliminate nearly all of the uncertainty associated with this vital risk assessment parameter. Additionally, although default baseline risk levels can fill the void that remains when sampling does not occur, there is a limitation to their use. The conservatism they offer is compromised as the number of nearby contaminating sources and the duration of their releases increase.

The second realization is that efforts to model contaminant concentrations in the environment demonstrate a repeated history of underestimation. A recent study evaluating the efficacy of food chain model predictions by numerous international teams supports this.[6] A decade after the 1986 Chernobyl accident, researchers set out to estimate quantities of Cesium (^{137}Cs), a fission product that readily assimilates in plant and animal tissue, and other released radionuclides, in environmental media a few hundred miles to the north in Finland. Knowledge of the time and location of the Chernobyl release, and the fallout being readily distinguishable from other environmental contamination, allowed for field measurements to be gathered at specific locations. A comparison of the predicted ^{137}Cs concentrations in agricultural products, freshwater fish, small and large game, and daily intakes (the same contaminant reservoirs evaluated in CSI risk assessments), and comprehensive field measurements of ^{137}Cs, revealed that the researchers had all produced underestimates. Other examples of fate and transport modeling underestimation are recent reports that the estimated global depositions to soil of chlorinated dioxins and

6 *See* Kathleen M. Thiessen et al., *Environmental Models Undergo International Test*, 31 Envtl. Sci. Technol. 358 (1997).

dibenzofurans, frequent risk drivers in CSI risk assessments, may be four to 20 times higher than the emissions from known sources.[7] Thus, it is reasonable to assume that CSI risk assessments are also predicated on underestimated constituent quantities in environmental media.

In the event that analytical chemistry cost is the driving force behind the guidances' non-requirement for background sampling, the logic for this argument is debatable in the case of a CSI. Construction and operation costs for a given installation-specific CSI will likely exceed $1 billion. Analytical chemistry costs for approximately 100 constituents in samples collected at a few select locations can be factored into a total project cost that is workable to all stakeholders. More importantly, this relatively minor expenditure would remove from CSI risk assessments their most conspicuous and unique of data gaps – a lacking background term.

A final related consideration concerns the ongoing practice of conducting trial, or test burns, of the few already constructed incinerators. The practice furnishes risk assessors with better data for the deposition modeling of stack emission constituents. The trial burns are themselves costly, approaching $500,000 each, as are the labor costs in having modelers and risk assessors process the successively refined data generated by the trial burns. A singular analytical chemistry round to provide the background constituents concentrations in soil and other media, at a significantly lower cost than a trial burn, would remove a substantial uncertainty surrounding the baseline risk level in a CSI risk assessment.

Estimated Surficial Soil Concentrations

The estimated soil concentrations of constituents released through CSI emissions represent the underpinning of the CSI risk assessment. Every exposure pathway to human and ecological receptors, other than inhalation, is fueled by the chemical-specific soil concentration term.

7 *See* Louis P. Brzuzy & Ronald A. Hites, *Global Mass Balance for Polychlorinated Dibenzo-p-dioxins and Dibenzofurans*, 30 Envtl. Sci. Technol. 1797 (1996); Joseph N.S. Eisenberg et al., *Chemical Dynamics of Persistent Organic Pollutants: A Sensitivity Analysis Relating Soil Concentration Levels to Atmospheric Emissions*, 32 Envtl. Sci. Technol. 115 (1998).

Given the dependency of the numerous risk outcomes on the soil concentration, it is imperative that the term not be underestimated.

In the absence of guidance specific to the CSI case, risk assessors have adopted the practice of assuming that constituent quantities in soil are maximal at the end of a CSI's period of performance. As a conservative measure, this calculated concentration is used in the risk assessments, and with the additional conservative assumption that this concentration does not change with time. I investigated the reliability of the estimated soil concentrations at a CSI's installation fenceline, produced when using the soil equations that are provided in the relevant guidance.[8] The focus of the investigation, for both a series of metals and the organic compounds that commonly appear as risk drivers in CSI risk assessments, was the chemical-specific loss terms of the equations.

In the case of metals deposited in the upper centimeter of soil, the soil equations describe two chemical-specific loss terms: runoff (ksr) and leaching (ksl). An approximate theoretical maximum upper centimeter concentration for the metals at the fenceline was first established for a recently assessed CSI that is scheduled to operate for 3.3 years. This was accomplished by using the soil equations and adjusting the soil loss term for the combined effects of runoff and leaching to a value of 1%. These theoretical maximum concentrations were then compared with the estimated installation fenceline concentrations recorded in the final risk assessment that had been prepared for that CSI.[9] The risk assessment's reduced concentrations, when compared with the theoretical maximum concentrations, are noteworthy as illustrated in Table 1. The equations appear to be exaggerating the fraction of deposited material that is lost from the soil system. For five of thirteen metals, for example, the guidance's equations are responsible for producing surface soil concentrations where there is more than a 92% reduction from the calculated theoretical maximum condition. More importantly, these significant losses represent surface soil concentrations potentially underestimated by as little as 25% to as much as 100 times.

8 *See* U.S. Envtl. Prot. Agency (April 22, 1994), *Errata* (1994), (December 14, 1994), (1996), *supra* note 3; Eisenberg, *supra* note 7; U.S. Envtl. Prot. Agency, *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities: Peer Review Draft* (1998).

9 *See* U.S. Army Center for Health Promotion and Preventive Medicine, *supra* note 5.

Table 1
Comparison of Estimated Soil Concentrations in Upper Centimeter at End of CSI's Period of Performance

Metal	*Theoretical Maximum Concentration* (mg/kg)*	*Estimated Concentration** Using Guidance (mg/kg)*	*Percentage Metals Loss (Runoff and Leaching) From Theoretical Maximum When Using Guidance*	*Ratio: Theoretical Maximum Concentration to Guidance-produced Concentration*
Antimony	4.51E-4	6.51E-6	98.6	69.3
Arsenic	1.15E-3	1.38E-4	88.0	8.3
Barium	2.4E-3	1.92E-3	20.0	1.25
Beryllium	3.03E-4	8.34E-5	72.5	3.63
Cadmium	4.81E-4	2.4E-4	50.1	2.0
Chromium	1.44E-3	1.11E-4	92.3	12.97
Lead	3.98E-3	3.98E-3	0.0	1.0
Mercury	6.95E-4	6.93E-4	0.0	1.0
Nickel	3.04E-3	9.59E-4	68.5	3.17
Selenium	4.61E-4	1.06E-5	97.7	43.5
Silver	1.49E-4	1.5E-6	99.0	99.3
Thallium	1.48E-2	4.3E-3	71.0	3.44
Tin	2.2E-4	2.2E-6	99.0	100.0

*Soil equation used is from Table B-1-1 (page 3 of 11) of U.S. Envtl. Prot. Agency (1998), *supra* note 8.
**See* U.S. Army Center for Health Promotion and Preventive Medicine, Final Screening Risk Assessment, Resource Conservation and Recovery Act Part B, *supra* note 5.

Based on this somewhat crude exercise, several difficulties arising from use of the guidance become apparent. First, the findings are not plausible. Realistically, such substantial quantities of metals would not be lost this quickly because it is their nature to largely be retained in terrestrial systems. Second, substantial losses did not occur for all metals. Lead and mercury exhibited no loss, which is the expectation for all of the metals. Although this paper's purpose is to identify inadequacies of supporting guidance for CSI risk assessments, and not to identify potentially faulty equation components, it appears that the default soil loss constant values provided in the guidance (for the combined runoff and leaching components), ks, are responsible for the excessive reductions in soil concentration. This is evident in Table 2 which provides both the ks values derived from guidance equations for the metals evaluated, and the estimated times for maximum surficial soil concentrations (i.e., from the end of the period of performance) to be reduced to a value that is 1% of that figure.[10]

Aside from confirming the losses reported in Table 1, another critical observation is now apparent. With concentration decays of two orders of magnitude for tin, silver, antimony, and selenium occurring in as little as three to 100 days after incinerator shut-down (i.e., when the contaminant source is removed), it appears that during CSI operation, the ks term is preventing these and other metals from attaining what would be vastly higher accumulations in soil by the time of CSI shut-down. In contrast, the estimated time from maximum concentration to 1% of maximum for lead and mercury extends to the thousands of years (see Table 2). This suggests that the default ks values for these metals significantly underplay the natural soil loss processes. Thus, the risk assessment's reported concentrations of these two metals are probably not underestimates, but rather overestimates.

Table 2
Metal Concentration Decay Following CSI Period of Performance

Metal	*ks*	*Effective Half-life in Soil (days)*	*Estimated Time for Maximum Concentration to Reach 1% of Maximum (days)*
Tin	566.900	2E-01	3
Silver	141.725	9E-01	10
Antimony	35.431	4E+00	50
Selenium	17.050	8E+00	100
Chromium	4.168	3E+01	400
Arsenic	2.594	5E+01	600
Beryllium	1.078	1E+02	2,000
Thallium	1.020	1E+02	2,000
Nickel	0.920	1E+02	2,000
Cadmium	0.472	3E+02	4,000
Barium	0.143	9E+02	10,000
Mercury	0.001	1E+05	1,000,000
Lead	0.009	2E+05	2,000,000

The ramifications of underestimated surficial soil concentrations are profound. All previous "passing" CSI risk assessments are reasonably suspect, especially those where borderline risk (e.g., an HI just below 0.25) was described. With exposure point concentrations having been underestimated, terrestrial exposures in turn, such as human consumption of homegrown vegetables, have undoubtedly been

10 *See* U.S. Envtl. Prot. Agency (April 22, 1994), *Errata* (1994), *supra* note 3.

underestimated as well. In a related observation, findings of acceptable risk at conventional combustion facilities may also be suspect, because of the under-reporting of metals in soil. This may suggest that re-evaluations at these facilities may be in order. Furthermore, the under-reporting of metals concentrations in soil impacts the assessment of risk at the aquatic components of a site. This is because the guidance, in part, uses the surficial soil concentration to estimate the surface water concentration of nearby onsite waterbodies. An underestimated surficial soil concentration also means that there is less metal available to migrate to surface water via runoff mechanisms, contributing to the surface water concentration.

Table 3
Comparative Soil Losses of Selected Organic Species Deposited by a CSI

Chemical	*Theoretical Maximum Concentration (mg/kg)*	*Estimated Concentration (mg/kg)* Using Guidance*	*Total Loss of Compound (%)*	*% Total Loss as ksg*	*% Total Loss as ksv*	*% Total Loss as ksr*	*% Total Loss as ksl*
TCDD (as 2,3,7,8 TCDD)	5.02E-9	3.89E-9	23.0	43.40	54.9	0.4	1.3
PCDD	3.24E-9	2.82E-9	13.0	81.03	15.7	0.7	2.5
HxCDD	4.02E-9	3.56E-9	11.5	94.00	5.7	0.1	0.2
HpCDD	4.48E-9	4.0E-9	10.7	98.49	1.4	0.0	0.1
OCDD	4.23E-9	3.79E-9	10.4	99.55	0.0	0.1	0.3
TCDF	1.16E-6	9.32E-7	19.7	51.70	45.6	0.6	2.1
PCDF	7.64E-4	6.65E-4	13.3	78.66	19.7	0.4	1.3
HxCDF	1.19E-3	1.05E-3	11.8	85.25	14.0	0.2	0.6
HpCDF	2.4E-3	2.10E-3	12.5	82.83	17.0	0.0	0.1
OCDF	3.08E-4	2.75E-4	10.7	99.88	0.1	0.0	0.0

* *See* U.S. Army Center for Health Promotion and Preventive Medicine, Final Screening Risk Assessment, Resource Conservation and Recovery Act Part B, *supra* note 5.

In the case of organic compounds deposited onto the ground, in addition to the previously described ksr and ksl, the guidances' soil equations include chemical-specific loss factors for degradation (ksg; for dioxin only) and volatilization (ksv). For the evaluation of the efficacy of the soil equations here, each of the four loss terms were set to a value of 1% to generate theoretical maximum concentrations for comparisons with values reported in the final risk assessment. As is evident from Table 3, the overall loss at the end of the period of performance appears reasonable, approximately 10% to 20%.

Furthermore, the percentage of the loss that is attributable to the combined effects of runoff and leaching is most minimal (0% to 3.2%). Unlike the metals, the organic compounds from CSI stack emissions are probably not being underestimated in the soil with the use of the relevant guidance. The analysis of the relative contributions of the four loss mechanisms, however, sheds some light on where the soil equations for metals may have gone awry. For the dioxins and furans evaluated, Table 3 shows the percentage of the total soil loss, as ksr and ksl, to be variable. In the case of the thirteen metals however, the partitioning of the soil loss, which is not shown, was found to be identical for each (with 22.4% attributed to ksr and 77.6% attributed to ksl), suggesting an idiosyncrasy of the equations.

Estimated Constituent Concentrations in Soil at Depth

CSI risk assessments commonly evaluate the indirect exposures of human and ecological receptors to soil constituents at depth when considering the consumption of below-ground and above-ground plants. In this context, the guidance recommends estimating constituent concentrations at the 20 centimeter depth, where plant root systems initiate the contaminant uptake process.[11] Chemical-specific root uptake factors are applied to estimate below-ground plant concentrations, and if needed, a below-ground-to-above-ground transfer factor is applied to achieve the tissue concentration in the plant's above-ground edible portions. As with the estimated surficial soil constituent concentrations, it is equally important that constituent concentrations at this critical depth not be underestimated. The finding of a potentially significant underestimation of metals concentrations in surface soils, noted above, suggested a complementary analysis to investigate the efficacy of the guidance's soil equations to produce accurate concentration estimates at the 20 centimeter depth.

As previously mentioned, risk assessors have inferred from the available guidance that media constituent concentrations are at their maximum at the end of a CSI's period of performance. Although this assumption is reasonable for certain exposures (e.g., inhalation and surface soil contact), it may not be reasonable for the plant

[11] *See* N.C. Dep't of Health, Env't, and Natural Res., *supra* note 3; U.S. Envtl. Prot. Agency (1990), (1993), (April 22, 1994), *supra* note 3.

consumption pathway of a CSI risk assessment. This is because a time lag of some order is necessary for the constituents to first appear at the 20 centimeter depth. Nevertheless, the guidance's soil equations are used routinely to compute 20 centimeter depth concentrations that are expected to occur when the CSI ceases operation. The only factor differentiating the equations used in computing constituent concentrations at variable soil depths is a singular term for soil mixing. Aside from the equations' simplistic method for estimating concentrations at depth, an additional method limitation is that it predicts constituent concentrations that linearly decrease with depth, an unlikely condition to arise in the field. Since sophisticated models exist that track the fate and transport of constituents in the vadose zone, the intent of the investigation was to compare metal concentrations at 20 centimeters achieved through modeling of the previously described theoretical maximum concentrations at the surface, with those produced using the guidance's equations. The results of the comparison, and two shortcomings of the guidance, are presented in Tables 4 and 5.

The modeling was implemented within the environmental software platform FRAMES[12] using the multimedia model MEPAS,[13] which includes source term and vadose zone models, as well as other transport, exposure, and risk assessment models.[14] The first piece of

12 *See* Gene Whelan et. al., *Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES)*, *in* Proceedings of the Workshops on Review of Dose Modeling Methods for Demonstration of Compliance With The Radiological Criteria for License Termination (T.J. Nicholson & J.D. Parrot, eds., 1998).

13 *See* Gene Whelan et al., *An Overview of the Multimedia Assessment Methodology MEPAS*, 9 Haz. Waste Haz. Mat. (2):1 (1992).

14 Regarding the source (i.e., the surficial soil concentrations that were modeled), several assumptions were made. The contamination was assumed to be uniformly distributed within the one centimeter thick topsoil control volume, and assumed to exist in the source prior to release. The porosity, bulk density, and infiltration (which includes irrigation) were assumed to be 20%, 1.5 g/cm3, and 97.98 cm/yr, respectively. The rate of contaminant release from the source through leaching was based on solutions to differential equations for Completely Stirred Tank Reactors, and was assumed to be auto-correlated to the mass remaining in the source, accounting for losses through volatilization, surface runoff, and natural degradation. As the contaminant inventory in the source decreased with time, the rate of release correspondingly decreased. Regarding transport, time-varying contaminant concentrations were calculated within the vadose zone at nineteen centimeters from the bottom of the source, using solutions to the one-dimensional, advective dispersing equation, and assuming constant infiltration and first order degradation, to account for losses from natural degradation. As with the source, porosity, bulk density, and infiltration were assumed to be 20%, 1.5g/cm3, and 97.98cm/yr,

useful information provided by the FRAMES-MEPAS modeling effort is that peak concentrations are achieved for nine of the ten metals shown in Table 4, some time after the end of the CSI's period of performance. Tin in the modeling exercise had no estimated accumulations occurring over an infinite time course. Furthermore, for all but one of the metals, this later occurrence still falls within the 30-year window of evaluation for effects that CSI risk assessments regularly consider. Thus it cannot be said that the risk assessments are necessarily evaluating the most conservative case, as the guidance-inferred assumption of worst case conditions occurring at the end of CSI operation, appears to be flawed.

Table 4
Comparison of Guidance-based and Modeled 20 cm Soil Concentrations (mg/kg)

Metal	*Guidance-based Concentration* at End of CSI Operation*	*Highest Modeled Concentration in First 30 Years Post CSI Operation*	*Ratio: Modeled/ Guidance-based*	*Occurrence of Modeled Post-CSI Operation Peak Concentration (years)*
Antimony	3.73E-05	2.95E-05	0.79	3.97
Arsenic	5.96E-05	7.48E-05	1.26	12.69
Beryllium	1.54E-05	2.37E-05	1.54	25.30
Cadmium	2.42E-05	3.36E-06	0.14	51.40
Chromium	7.96E-05	9.37E-05	1.18	9.11
Nickel	1.54E-04	1.97E-04	1.28	29.10
Selenium	2.98E-05	3.02E-05	1.01	4.75
Silver	3.16E-05	9.76E-06	0.31	3.47
Tin	1.34E-4	0.0	-----	-----
Thallium	7.54E-04	9.63E-04	1.28	27.10

* *See* U.S. Army Center for Health Promotion and Preventive Medicine, Final Screening Risk Assessment, Resource Conservation and Recovery Act Part B, *supra* note 5.

A second finding evident in Table 4 is that there are five cases where the FRAMES-MEPAS modeled concentration of a metal is greater than that resulting from the guidances' use. Although the modeled concentrations are only 18% to 54% higher, the overall risk could be influenced by these increases. Furthermore, an evaluation of a broader suite of analytes could reveal more cases of this phenomenon, and

respectively. *See also*, Warren Viessman, Jr. & Mark J. Hammer, Water Supply and Pollution Control (4th ed. 1985).

perhaps with greater ratios of modeled-to-guidance-driven concentrations than shown in this paper. An additional noteworthy finding is that the five metals with greater modeled concentrations than guidance-based ones, have their peak concentrations occurring at more than just one or two years post-CSI operation. This is unlike the pattern displayed by those metals where the guidance-based concentrations were higher than the modeled ones (e.g., antimony and silver).

The modeling exercise reveals another contamination pattern feature (see Table 5) for metals at depth. For barium, lead, and mercury, there are no accumulations at the 20 centimeter depth during the 30-year window of interest. This is not to say that these metals never appear at lower soil strata. Rather, after a considerable time lag, ranging from the hundreds to the thousands of years, these metals do occur at the 20 centimeter depth, and at concentrations similar to the other metals that had their peak concentrations occur much earlier (Table 4).

Table 5
Comparison of Peak 20 cm. Soil Concentrations (mg/kg)
and Their Occurrence for Certain Metals

Metal	Peak Concentration in First 30 Years Post CSI Operation	Highest Concentration Achieved at Any Time	Occurrence of Highest Modeled Concentration (Years Post CSI Operation)
Barium	0.0	1.56E-04	170.3
Cadmium	3.36E-6	3.13E-05	51.4
Lead	0.0	2.59E-04	27,603.0
Mercury	0.0	4.52E-05	16,800.0

The long delay until lead and mercury's detection at 20 centimeters corroborates the finding above — that these two metals have surficial soil concentrations that essentially match the theoretical maximum concentrations that were constructed. As these two metals demonstrate such a high degree of retention at the surface, their eventual appearance at 20 centimeters, and especially their attaining peak concentrations there, would be expected to be greatly time-shifted. To the extent that all metals should have had significantly higher surficial soil concentrations at the fenceline at the end of the period of performance, this lengthy delay until appearance at 20 centimeters would be

expected for them as well. In the case of cadmium, however, Table 5 indicates a different condition. Here the peak concentration occurring overall, at 51.4 years post-CSI operation, is nearly an order of magnitude higher than that which occurs during the first 30 years after CSI operation. Although other metals may not be of interest so many years post-CSI operation, cadmium and other analytes of the CSI emission stream might first contribute (significantly) to risk at this advanced time.

Fenceline Risk

The available guidance recommends that risk assessments adopt the approach of assuming human receptors of concern are situated at an installation's fenceline where, as previously mentioned, constituent concentrations are assumed to be at their maximum.[15] Thus, CSI risk assessments evaluate hypothetically placed receptors, such as subsistence farmers residing downwind of the proposed incinerator at the installation's perimeter, although the fenceline may not be a reasonable location for them. Undeniably this approach is highly conservative, because maximum exposure scenarios are sometimes artificially constructed. One would expect the guidance to recommend evaluating risk to ecological receptors at the fenceline as well, if for no reason other than to maintain parity between the two evaluations. The analysis here, however, shows a disconnect between the level of conservatism sought after in the human health and ecological risk assessments at CSI.

None of the final available risk assessment guidance documents for combustion incinerators address the assessment of ecological risk, other than their recommending that estimated constituent concentrations in surface water be compared to relevant water quality criteria for the protection of aquatic species. A CSI risk assessment could potentially ignore all conventionally evaluated exposures that occur within ecosystem components (e.g., terrestrial food-chain effects), and still be termed a complete effort. For CSI risk assessments already produced, "passing" determinations may not have factored in any more ecological considerations than the surface water comparison mentioned above.

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15 *See* U.S. Envtl. Prot. Agency (1990), (1993), (April 22, 1994), *supra* note 3.

Putting this situation aside for the moment, current guidance in draft significantly expands on the dimensions that ecological risk assessments should take when assessing risk at combustion facilities.[16] The guidance recommends identifying ecosystems and sensitive habitats in the "assessment area." Although the intent is to identify appropriate receptors and sensitive habitats within the critical 50-kilometer radius of an incinerator, there is the potential for ecological risk to be underestimated with this practice. Through implementing the draft guidance, the mapped areas of desirable ecosystems and sensitive ecological habitats could all fall beyond the fenceline, and possibly far from the proposed CSI site. Since there is no required number of communities to be evaluated, and no requirement that receptors be evaluated at or within the fenceline, ecological receptors that invariably occur there can be overlooked. Whereas hypothetically placed human receptors are evaluated at the fenceline, ecological receptors almost assuredly located there may not be.

Frequently, habitat quality is reduced when it lies within close proximity of areas with a high degree of human activity. Terrestrial habitat at an installation's fenceline therefore may well reflect human-induced disturbances. Although habitat quality at the fenceline may be significantly reduced when compared with more optimal locations beyond the fenceline but still within the assessment area, it is unlikely that the installation fenceline is devoid of ecological receptors that are commonly selected as assessment endpoints and their prey. Terrestrial food chains centered about the fenceline then (where maximum constituent soil concentrations are assumed) are reasonable to consider, even if the ecological risk assessments performed are no more than screening level assessments. For this reason, such evaluations are routinely performed in conventional (i.e., post contaminant-release) risk assessments at Army sites. Failure to evaluate the common terrestrial food chain of the soil-invertebrate-small-rodent-raptor (where applicable at a CSI installation's fenceline), for example, is to bypass an opportunity to evaluate risk where it may be greatest. This is the clear intent of the evaluations of human exposures at the fenceline.

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16 *See* U.S. Envtl. Prot. Agency, *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities: Peer Review Draft* (1999).

Discussion

The issues presented above strongly suggest that several inadequacies are apparent in the guidance documents used to support CSI risk assessments. These inadequacies may stem from the assumption that the existing guidance, developed for use with conventional incinerators, is also applicable to the CSI case. As a consequence of the guidances' use, the conservatism the risk assessments are intended to display appears to be compromised; potentially "pass" determinations may in fact be "fails." However, it may be that the demonstrated cases of lacking conservatism are relatively insignificant, outweighed by other truly conservative features in the assessments, whether these follow from the use of the guidance cited or not. As an example, an assumption that may be made in CSI risk assessments is that all metals released in stack emissions are in their most toxic form. Employing this assumption could override the underestimated metals concentrations in surface and subsurface soils reported here. A sensitivity analysis of the numerous assumptions provided in the various guidance documents would first have to be conducted to see how critically the observations made in this paper impact on the overall outcome of CSI risk assessments.

The four issues discussed above should nevertheless be considered for two reasons. First, they identify approaches that can be taken to increase the level of trust in CSI risk assessment outcomes, where the risk assessor is confined solely to the use of predictive methods, and yet needs to feel confident that the "pass" case of a pass-fail determination scheme assures health protection. Second, the identified deficiencies are all easily reparable. Approaches to improve upon the uncertainties created by the guidance are discussed below.

Regarding the practice of assigning a default baseline risk level for the pre-CSI start-up condition, there is ample reason to suspect that this is not sufficiently protective. Since soil and other media cannot be sampled for CSI emission stream constituents (the CSI is not built yet), a risk assessor for a CSI can ill-afford to not know the baseline condition. Thus, where there is an opportunity of any sort to incorporate real-time data, logic dictates that it should be seized. Although it may be suggested that the true intent of a CSI risk

assessment is to document risk levels associated with the facility only (i.e., independent of all other nearby contaminant influences), this does not follow from the guidance. In defining the trigger levels that denote unacceptable risk (e.g., the HI threshold of 0.25), the guidance demonstrates openly that the case to consider is that of a CSI in a context of area-wide contamination stemming from other sources. In light of the above, it would be prudent to have a sampling requirement to characterize the pre-operation condition for a CSI. As to where sampling locations for a baseline analysis should be placed, the installation fenceline is the most obvious choice. As the current guidance recommends evaluating scenarios at the fenceline for human health risk, even when actual receptors are not situated there, sampling at the fenceline would be most the logical choice.

The apparently faulty equations for estimating metal concentrations in surface soil suggest several recommendations. Early attention to making all necessary corrections is one essential task. It would seem that an indispensable task prior to estimating concentrations for the end of the period of performance would be to plot constituent concentrations beginning with CSI start-up and throughout a 30-year window. Such an effort is not typically performed when conducting CSI risk assessments due to the interest in knowing the concentration only at the end of the period of performance. By plotting the information, it would become immediately obvious if the patterns of constituent increase and decay are reasonable. At a minimum, and for at least a first tier assessment, it is also recommended that theoretical maximum metals concentrations (similar to those produced here) be used in each soil concentration-based scenario under evaluation. Risk assessments that "pass" under these worst-case conditions would supply the needed confidence that current CSI risk assessments are lacking.

The seemingly underestimated constituent concentrations at the 20 centimeter soil depth and the misidentified occurrence of maximum concentrations at this depth can also be easily remedied with the use of scientifically defensible vadose zone models (e.g., the FRAMES-MEPAS system) that can well simulate natural fate and transport processes. These systems can incorporate more site-specific factors than the equations supplied in the guidance. Unlike the equations supplied in

the available guidance, these models are easily able to identify the time at which maximum constituent concentrations occur at depth. To the extent that the CSI risk assessments intend on evaluating a worst-case condition, the theoretical maximum surface concentrations are those to be fed into an appropriate vadose zone model. With this approach it may become evident with the other CSIs to be evaluated that the 30-year window commencing with CSI start-up is not that which needs to be assessed for risk potential when seeking a CSI construction permit. Importantly, given the time-lags until maximum constituent concentrations are achieved in subsurface soils, and the variable behavior of metals in this regard, the merits of evaluating the worst-case scenario may need to be reviewed. The reasonable maximum exposure scenario may, with due consideration, prove to be more applicable to the decision-making process.

If it is assumed that constituent concentrations and exposures are maximal at the CSI installation fenceline, then ecological receptors need to be evaluated at this critical location. As a means of bolstering the ecological risk assessments that follow from use of the available guidance, including guidance in draft, it is suggested that such evaluations occur routinely. Furthermore, for the sake of maintaining parity with the human health risk assessments for CSI, ecological assessments should be centered about the installation fenceline, even if available information indicates that key receptors are not found there.

Conclusion

In light of the preceding discussion, improvements to the current risk assessment methodology should be made. Several points support this recommendation. First, it is clear from the reading of the guidance that short-term operation combustion facilities are not their focus. Second, CSI risk assessments have features that decidedly differ from those of the conventional incinerator case, including their predictive nature, evaluation of unique feed components, and evaluation of as many as four independent furnaces that contribute to emissions. The non-attention of the present guidance to these features may be responsible for rendering inaccuracies in CSI risk estimates. Ample time does not exist, however, to address these differences with the creation

of a CSI-specific companion to the existing library of combustor facility guidance. Given the approaching Chemical Weapons Convention deadline for destruction of the entire chemical stockpile, it would be prudent to ensure that the current guidance is not enforced verbatim for the CSI case. Where there are opportunities for introducing improvements to the guidance, these should proceed in a site-specific manner.